The strength of functional connectivity between the frontoparietal and default mode systems correlates with behavioral performance on a variety of tasks in the Human Connectome Project

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Introduction

The brain meets myriad cognitive challenges on a daily basis. It is commonly appreciated that performance in distinct cognitive tasks tends to be supported by distinct networks of functionally connected areas in the human brain. More recently, it has also been suggested that such task-specific systems may be complemented by a task-general or multiple-demand system (MDS) that supports performance across many different types of tasks (Cole et al., 2013). The activity of both the MDS and DMS seem to be important across a wide range of tasks – during externally cued tasks, the MDS is activated, and the DMS is deactivated (Fox et al., 2005; Liang, Zou, He, & Yang, 2015). Conversely, during internally focused tasks or processes, the MDS is inactive and the DMS is active (Liang et al., 2015). Furthermore, in several externally cued tasks including executive function (Li, Yan, Bergquist, & Sinha, 2007; Zou et al., 2013), reaction time (Barber, Caffo, Pekar, & Mostofsky, 2017), and attention (Gui et al., 2015), DMS deactivation and MDS activation relates to improved behavioral performance. This suggests a common pattern of DMS-MDS activity affects behavioral performance across different types of externally cued tasks. Additionally, several studies have demonstrated that the functional connection between DMS and MDS is significantly negatively correlated with individual behavioral performance on executive function tasks (Satterthwaite et al., 2013; Sala-Llonch et al., 2012; Kelly, Uddin, Biswal, Castellanos, & Milham, 2008). However, the importance of this connection in other cognitive domains is not well understood. Here we test the hypothesis that the functional connectivity pattern between these two systems similarly affects performance on externally cued tasks including and beyond executive function. Specifically, we seek to determine whether the strength of connectivity between the MDS and DMS is correlated with behavioral performance on suite of externally cued tasks.

It is established that DMS and MDS are involved in nearly all tasks, but it is not yet known if or how the two systems interact in a consistent way during all types of externally cued tasks, or alternatively if the interaction is dependent on the specific externally cued task. If the relationship is consistent across externally cued tasks, it would support the theory that the brain groups externally cued tasks and has a common mechanism to complete them (Vanhaudenhuyse et al., 2011). If no common relationship exists, perhaps more functional complexity exists within the highly active MDS and inactive DMS configuration, with this activity configuration able to support different types of task-specific functional relationships.

Keywords: fask fMRI; functional connectivity; frontoparietal system; default mode system

Results and Discussion

Here, we investigate the hypothesis that functional competition between the MDS and DMS promotes improved behavioral performance on externally cued tasks. To test this hypothesis, we examined resting state fMRI data from 801 subjects in the HCP (Van Essen et al., 2013) collected during the performance of 5 distinct tasks requiring working memory, relational processing, emotion processing, language processing, and social cognition. Behavioral performance in working memory was summarized by the mean accuracy across 0-back and 2-back tasks. Performance on the relational task was summarized as the accuracy across both the matching and control conditions. Performance for the language task was taken to be the maximum difficulty reached across both the language and math conditions. For the social task, performance was defined as the percentage of correctly identified random interactions that were not social interactions. Finally, performance on the emotion task was summarized as the accuracy across both the shape and face conditions.

For each of the 5 tasks, we calculated the correlation between the strength of the MDS-DMS functional connection and performance across subjects (Fig. 1 A, B). To do this, we applied a 400 region parcellation (Schaefer et al., 2017), calculated the pairwise Fisher-z transform of the Pearson correlation, and normalized the matrices by their total weight. We found that the strength of the functional connectivity between the DMS and the frontoparietal system (FPS; a subset of MDS) was significantly correlated with behavioral performance on 4 of the 5 tasks (all but the task demanding emotion processing). Importantly, this connection strength was consistently *negatively* correlated with behavioral performance measures. This relationship is observed in 4 different tasks, implying that it may not be driven by the particular demands of

each task, but rather driven by the challenge of task completion, regardless of the specific task. Such a line of reasoning is supported by three observations: first, it has been suggested that a strong anti-correlation between the MDS and DMS may efficiently suppress DMS activity (Kelly et al., 2008). Second, evidence exists that activation of the DMS decreases attention to external stimuli by redirecting attention to introspective thoughts (Uddin, Clare Kelly, Biswal, Xavier Castellanos, & Milham, 2009). Third, it has been observed that the DMS-MDS functional connection strength varies according to the presence or absence of a task demand, and that functional DMS connections are related to individual behavior during task performance (Elton & Gao, 2015). The current findings are consistent with these three arguments: decreased DMS activity is necessary for efficient task completion, and may be suppressed by a strong MDS-DMS anti-correlation - such a configuration would be helpful in a wide variety of tasks, which we demonstrate with the present findings. We suggest that this particular connection may play an important role in a functional network supporting performance on externally cued tasks.

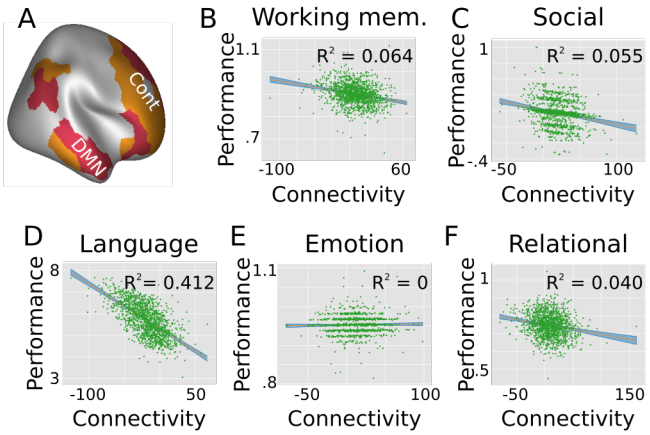

Figure 1: The strength of functional connectivity between the DMS and the FPS is correlated with individual differences in behavior across subjects. (A) We examine specifically how the strength of functional connectivity between the default mode network and frontoparietal system relates to behavioral performance. Panels B – F show the relationship between (i) the strength of functional connectivity between the DMS and FPS, and (ii) behavioral performance measured and summarized on all 5 tasks. The units of performance as well as connectivity are detailed in the text.

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